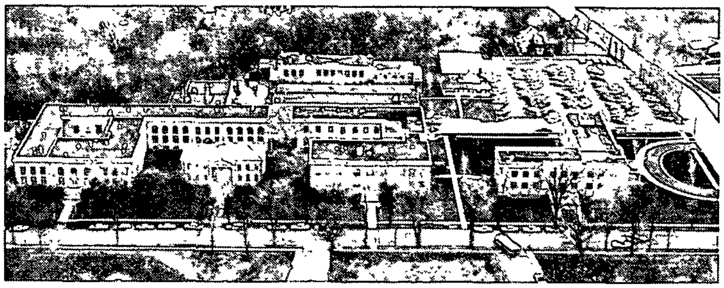

THE INSTITUTE OF PAPER CHEMISTRY, APPLETON, WISCONSIN

IPC TECHNICAL PAPER SERIES

NUMBER 154

FACTORS AFFECTING THE OUTLOOK FOR UTILIZATION OF HARDWOODS IN PULPING AND PAPERMAKING

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MAY, 1985

Factors affecting the outlook for utilization of hardwoods in pulping and papermaking

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ABSTRACT

Factors likely to affect the extent of hardwood use for pulping are reviewed. Following consideration of the distinguishing characteristics of hardwood pulps, the current use in various products is outlined and the outlook for those products is reviewed. Emerging technology likely to have an impact on future hardwood use is discussed with reference to chemimechanical and chemithermomechanical pulping, genetic tree improvement and press drying. It is concluded that the pulp and paper industry will make increased use of hardwood species in the future.

Introduction

Historically, there has been a tendency within the pulp and paper industry to regard hardwoods as inferior raw material for papermaking. This perception arises chiefly from the fact that, compared to softwoods, they do not make as strong a sheet of paper. The strength difference must, however, be viewed in relation to increasingly important advantages that hardwoods possess over softwoods: a combination of properties such as smoothness and opacity that makes hardwood pulps particularly suitable for inclusion in furnishes for printing grades, the unique suitability of hardwood semichemical pulps for corrugating medium, and the relative abundance of hardwood species in many parts of the United States. The last has important economic implications, especially in view of the growing scarcity of softwoods in some parts of the country.

The aim of the present paper is to provide insight into the nature of the factors affecting the utilization of hardwood for pulping, and to show how they may be expected to combine to determine future use of this resource. In addition, some capacity addition is reviewed to exemplify near-term changes, and some new technology that may impact the future of hardwood pulping is described.

Distinguishing characteristics of hardwood pulps

The chemistry and morphology of hardwoods differ markedly from those of softwoods in several respects. Most of these differences have strong implications for the ease of manufacture and the properties of the pulps made from them. In comparison to softwoods, they have

* high carbohydrate content with much interspecies variation
* more readily removable lignin

* greater diversity of cell types
* short fibers
* greater fiber wall thickness relative to fiber diameter
* more cohesive fiber wall structure.

Depending on the species, the higher carbohydrate content can result in higher yields of pulp from the chemical pulping processes, such as kraft. Aspen, for example, gives substantially higher kraft pulp yields than softwoods. The more readily removable lignin translates to faster and more complete delignification during pulping and bleaching. This is an asset when the wood blend being processed contains little or no softwood, but may result in harmful nonuniformity when mixtures of softwood and hardwood are processed together (1).

It is the physical characteristics of hardwood fibers that distinguish them from softwoods more sharply than chemical ones. The most obvious of these is fiber length. Whereas softwood fibers are typically 3 mm or greater in length, hardwood fibers are seldom greater than 1.5 mm and usually much shorter. This fact has important consequences in terms of paper properties; relative to softwoods, hardwood pulps give

* lower tensile strength. This is most evident in pulps in which the degree of interfiber bonding is limited, such as mechanical pulps. When a sheet made from such a pulp fails in tension, it does so more as a result of fibers pulling out from the network structure than of fiber breakage. At a given level of specific bond strength, the resistance to fiber pullout is roughly proportional to fiber length. This effect, though less pronounced, is still quite evident at the levels of bonding typical of papers made from bleached chemical pulps.

* lower tear strength. Resistance to tearing, as usually measured, is a measure of the work done in propagating the tear over a given distance. The work done in breaking a fiber is negligibly small in comparison to that required to pull a fiber out of the network, so fiber pullout is the dominant phenomenon determining tear strength. Below some critical level of bonding that marks the onset of fiber breakage, tearing resistance is theoretically proportional to the square of the fiber length.

Next to fiber length, the most apparent morphological difference between hardwoods and softwoods is the greater diversity of cell types in the former. This also has strong implications for the strength of paper made from them. Vessels and ray cells do not contribute very much to paper strength and may give rise to other problems such as the picking of vessel elements from the surface of the sheet during printing operations. The short ray cells are a source of granular fines that, unlike the fibrillar fines originating in the fibers, have little beneficial effect on interfiber bonding. As a result of the relatively high content of nonfibrous elements, the proportion of load-bearing fibers in the sheet is reduced and the strength is lower than for softwood sheets.

The high fines content of hardwood pulps, in addition to causing the problems mentioned above, is responsible for some unique advantages. It contributes to better smoothness, sheet formation, opacity and printability. As a result, hardwood pulps are outstanding raw materials for printing and writing papers.

Hardwood fibers, besides being shorter, are more slender than softwood fibers. In addition, the thickness of their walls is generally the same or greater than in softwoods. Consequently, they do not collapse as readily into the ribbonlike form that maximizes interfiber contact area, and the degree of bonding is less than in softwood sheets. Another factor contributing to this bonding deficiency, especially in mechanical pulps, is the different response of the hardwood fiber wall to mechanical action (2,3). In softwoods the primary wall and outer layer of the secondary wall, S1, are readily removed and the S2 layer becomes extensively fibrillated. This fibrillation extends the surface of the fiber, exposes new surface well disposed toward bonding, and probably makes the fiber wall more flexible. Some fibrils and lamellar assemblages of fibrils are also removed from S2, forming fibrillar fine material that contributes effectively to interfiber bonding. This process does not occur as readily in the case of hardwoods because the primary wall and S1 layer are more difficult to remove. This may be because of stronger bonds between cell wall layers, as claimed by Giertz (2), or because the S2 layer is thicker, as determined by Marton et al. (3) and shown in Table I.

(Table I here)

In summary, the chemical and morphological differences between hardwoods and softwoods result in the former giving pulps that are somewhat inferior in strength properties but superior in ease of delignification and properties important in printing grades. These advantages, together with increasingly important wood cost and supply advantages' have resulted in steadily increasing utilization of hardwoods and have provided the incentive for technological advances likely to further increase their utilization.

Uses, production and outlook

A wide variety of paper and board products contain hardwood. Bleached hardwood pulp goes into such high value products as printing and writing grades, folding boxboard, tissue and toweling. Unbleached hardwood semichemical pulp is the major ingredient in corrugating medium. Even kraft linerboard can contain 10-15% hardwood (1). In addition, high-yield hardwood pulps are increasingly finding their way into publication grades.

In 1983, some 46.5 million tons of paper grade pulp were produced in the U.S. Bleached hardwood kraft accounted for 8.8 million tons, and corrugating medium for 3.5 (13). This compares to 10.4 million tons of bleached and 17.8 million tons of unbleached softwood kraft made in the same period. The growth rate is anticipated to be 2-3% per annum.

The consumption of hardwoods for pulp has grown dramatically over the years since 1940 according to U.S. Forest Service assessment, as reported by McGovern (4). As shown in Figure 1, the hardwood portion of total pulpwood consumption increased from 13.6% in 1950 to 26.6% in 1974. Growth was halted by the 1975 recession and has since resumed, albeit at a somewhat lower rate.

(Figure 1 here)

Nationally, approximately 27% of the total pulpwood produced is hardwood. In some parts of the country, however, the percentage is much higher. Wisconsin, for example, has 14.5 million acres of forest land of which only 17% have softwoods as major timber types (5). This has resulted in a significant shortage of softwood for the paper industry, with softwood production being only 0.62 million cords out of a total of 2.47 million cords in 1983 (6). Table II compares the Wisconsin figures with those for the nation as a whole.

(Table II here)

Growth in hardwood pulpwood production is expected to continue and to outpace that of softwood, both nationally and in hardwood-rich areas such as Wisconsin (Table III). The hardwood percentage in the United States, as estimated by the anticipated demand changes, will grow from 26.6% in 1978 to 29.4% in 1990 (7). This corresponds to an annual rate of growth in hardwood share of 0.8%. The hardwood share in Wisconsin is expected to increase from 74.9% in 1983 to 81.0% in 1990, an annual growth rate of 1.1%.

(Table III here)

New hardwood pulping capacity

It is likely that the expansion plans of many paper companies will include increased use of hardwoods. One example is the new pulp mill of Champion International currently being built at Quinnesec, Michigan (8). The mill, slated for 1986 startup, will produce some 750 tons/day of bleached hardwood market pulp. This translates to roughly 515,000 cords/year of birch and maple. It is expected that 65% of the wood will be purchased from private wood lots, most as 100-inch roundwood. In addition, 150,000 tons/year of wood will be needed for energy generation in the hogged fuel boiler. Thus, one new mill can have a significant impact on hardwood utilization.

Other mills have announced expansion of existing facilities that will increase hardwood requirements. These include hardwood chemical pulp production for use in printing grades. For example, Consolidated Papers, a major producer of printing grades, has expansion programs that will roughly double chemical pulp production. Expansions will also affect mechanical pulp production and paper machine capacity.

In summary, the installation of significant new capacity for current products requiring hardwood pulp will lead to an increased demand for hardwoods in the very near future.

New technology

Factors likely to affect the degree to which hardwoods are used for pulp and paper manufacture include market characteristics, relative availability and cost of softwood and hardwood, and technological changes allowing products of higher quality to be made from hardwoods. Three new technologies which may be placed in the last category are hardwood chemimechanical and chemithermomechanical pulping, genetic tree improvement and press drying.

Chemithermomechanical and Chemimechanical Pulping

A major development in the field of mechanical pulping that occurred during the early 1970's was the advent of thermomechanical pulping. Traditionally, nearly all mechanical pulp had been made by the stone grinding of logs. During the 1960's it was shown that superior pulps could be made from chips in disk refiners, and from there it was a short step to the development of chip refining at pressures above atmospheric. Pressurization of the refiner allowed the temperature to be controlled at a point just below the glass transition point of lignin. This reduced the amount of fiber damage accompanying fiber separation and had beneficial effects on the mode of separation and fiber surface development. The resulting effect on the properties of pulps made from softwoods was dramatic, as illustrated by the data for spruce stone groundwood (SGW) and pulp made by the new process, called thermomechanical pulp (TMP) in Table IV.

(Table IV here)

Unfortunately, as illustrated by the aspen data in the same table, the effect on hardwood pulp properties was not of similar magnitude. This development appeared to widen the already well-recognized gap in quality between softwood mechanical pulps and the corresponding hardwood pulps, as further illustrated in Table V. The data in this table also serve to show that substantial differences exist between the properties of mechanical pulps made from different species, and that the problem of utilization of the dense hardwoods was particularly acute.

(Table V here)

The advent of the strong refiner pulps renewed interest in high yield pulping research and, in particular, in the prospect of achieving greater strength gains by incorporating mild chemical treatments into the pulping process. Recognizing that the hydrophobic character and brittleness of lignin limited the strength of the pulps, researchers experimented with chemicals that would modify the lignin to alleviate both of these undesirable characteristics. These included alkali, sodium sulfite, sodium bisulfite, ozone and others. In some processes, sodium sulfite also served to prevent the discoloration of the pulp which would otherwise occur under the alkaline conditions favorable for pulp strengthening. In others, hydrogen peroxide served the same purpose and also offered the possibility of modifying the process to improve the brightness as well as the strength of the pulp. The processes also differed with respect to the point of chemical addition, which could be before the first of a series of refining stages (usually two), between the first two stages, or after the last. These processes fell into categories called chemimechanical pulping or chemithermomechanical pulping, depending on whether or not the first stage of refining was conducted at superatmospheric pressure.

From the standpoint of increased hardwood utilization, the outcome of this work was favorable. In general, hardwoods responded to chemical addition to a greater extent than softwoods, with the result that valuable pulps could now be made from most hardwood species. As shown in Table VI, the relatively long-fibered species, aspen and birch, produced pulps which could be considered as replacements for premium quality SGW. Even the more difficult high-density species such as maple and oak gave pulps with attractive properties, and mixed high-density hardwoods gave a very strong, bright pulp that had properties not very far removed from those of a typical hardwood kraft pulp. Even when compared to the usually slightly stronger softwood CTMP and CMP (Table VII), the hardwood pulps exhibited an advantage in the form of higher brightness, which is especially valuable in formulating furnishes for printing and writing grades.

(Table VI and VII here)

Another recent finding that augurs well for hardwood utilization is the observation by Mutton and co-workers of synergism when sulfite-treated softwood and hardwood chips are refined together. Their data are reproduced in Table VIII. Forty percent or more of a dense hardwood mixture can be included in the wood blend, with no apparent loss in strength compared to 100% softwood pulp.

(Table VIII here)

In summary, the development of chemithermomechanical and chemimechanical pulping processes has provided a new and attractive means of utilizing hardwoods for paper. Pulps capable of replacing softwood mechanical pulps in mixed furnishes can be made from most species. In some cases the resulting pulps are sufficiently strong to compete with softwood chemimechanical pulps or to partially replace chemical pulps. In addition, large amounts of hardwoods can be included in blends with softwoods destined for chemimechanical pulping, with no adverse effect on pulp properties.

Genetic Tree Improvement

Another developing technology which may have a positive impact on the extent to which hardwoods find their way into paper and board products is genetic tree improvement. This may take the form of mass propagation of superior trees, either by tissue culture or vegetative methods, hybridization followed by mass propagation, or gene manipulation. The aim of all of these techniques is the same - to produce large numbers of very similar trees with unusually desirable characteristics.

An example of a currently available product of research in this area is the successful development of triploid hybrid aspens at The Institute of Paper Chemistry (14). These trees, which are presently being released, were produced by crossing highly selected diploid female *P. tremuloides* with a single tetraploid *P. tremula* male tree growing in southern Sweden. This cross was first made in 1958 and since then has been repeated a number of times using 8 to 10 different female trees. The growth rate and wood and pulp properties have been evaluated in four replicated field plantings and several demonstration plantings.

A few of the results of these evaluations are set out in Table IX to illustrate the main points of superiority of the hybrids over native aspen. These are growth rate and fiber length, the latter being manifested in pulp properties as markedly improved tear strength. The improvement in pulp properties narrows considerably the gap in quality between aspen and softwood kraft pulps.

(Table IX here)

Recent advances in the tissue culture selection and propagation of disease resistant aspen (16) suggest that on medium quality hardwood sites, aspen with improved wood quality could be grown at growth rates approximately three times as fast as native aspen (300 ft^3/acre/year *vs.* 100 ft^3/acre/year). Extensive use of this source of fiber could greatly reduce the number of acres required to supply a mill or make possible expansion of mill production with no increase in supporting land base.

These developments offer the possibility of plantations of superior trees close to the mill site, which would have the beneficial effects of reduced wood transportation costs, reduced harvesting costs because of increased uniformity and volume per acre, and improved pulp quality. This, and the likelihood of introduction of other deciduous hybrids, will contribute to the expected increase in hardwood utilization for pulp.

Press Drying

Press drying consists of drying a paper web by the simultaneous application of heat and pressures in the range 500 to 1000 kPa. In the process, lignin and hemicellulose are softened sufficiently to allow them to flow to some extent. This, in combination with the applied pressure, leads to an increase in bonded area and ultimately, improved wet and dry strength, including compressive strength, which is so important for containerboard applications. It is hypothesized that the hemicelluloses give the improved bonding and strength, whereas the lignin sets around the bonds, reducing their susceptibility to moisture. When hardwoods such as oak are used, linerboard properties are similar to or better than those of conventional linerboard, as illustrated by the data in Table X (15). Combined boards made from linerboard and corrugating medium, both of which have been press dried, are also similar to the corresponding conventional boards (Table XI).

(Table X and XI here)

Problems remain in developing a continuous commercial system for press drying. However, once these are solved, use of hardwoods in linerboard could increase significantly, especially if 100% hardwood linerboard proves feasible.

Conclusion

The utilization of hardwood species for making pulp will continue to grow at a rate faster than that of softwoods. This will be the combined result of emerging technology that promises to reduce the strength disadvantage of hardwood pulps, their superiority in some applications, and an increasingly favorable supply situation.

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I. Thickness of the outer layer of the secondary cell wall in Norway spruce and some hardwoods according to Marton et al. (3)

	S1 Thickness, μm
Norway spruce	
Earlywood	0.13
Latewood	0.18
White birch	0.21
Maple	0.23
Red oak	0.22
Eucalypt	0.36
Poplar	0.12

II. Pulpwood production in the U.S. and Wisconsin

	Millions of cords/year			
	Total	Hardwood	% Hardwood	Reference
United States (1978)	79.8	21.2	26.6	(4)
Wisconsin (1983)	2.5	1.85	74.9	(6)

III. 1990 Pulpwood production in the U.S. and Wisconsin.

	Millions of cords/year		
	Total	Hardwood	% Hardwood
United States[a]	111.6	32.8	29.4
Wisconsin[b]	3.0	2.43	81.0

[a]Estimated by anticipated growth in demand (7).
[b]Assumes total growth rate same as that corresponding to the figures shown for the U.S., and 4% growth in Wisconsin hardwood pulpwood production (5).

IV. Properties of stone groundwood (SGW) and thermomechanical pulp (TMP) from spruce and aspen (9)

	Spruce		Aspen	
	SGW	TMP	SGW	TMP
C.S. Freeness, mL	54	85	80	86
Breaking length, km	3.6	5.3	2.6	3.0
Tear index, mN • m^2/g	5.6	9.8	3.7	4.3
Opacity, %	98	93	99	96

V. Properties of TMP from hardwoods

	Spruce	Aspen	Birch	Sugar Maple	Oak
C.S. Freeness, mL	54	86	90	90	90
Breaking length, km	5.3	3.0	2.1	2.0	1.0
Tear index, mN $\cdot$ m^2/g	9.8	4.2	2.5	1.6	1.7
Brightness	64	61	39	46	31
Reference	(9)	(9)	(3)	(3)	(3)

VI. Properties of CTMP from hardwoods

	No. Sftwd. SGW	Aspen	Birch	Maple[a]	Oak	No. Hdwds[b]
C.S. Freeness, mL	54	91	90	350	100	350
Breaking length, km	3.6	4.4	4.1	2.9	2.9	4.8
Tear index, mN • m^2/g	5.6	5.9	4.6	3.0	5.4	6.6
Brightness	60[c]	59	66	61	43	72
Opacity	98	93	n.a.[e]	89	97	n.a.
Process[d]	SGW	ASP	APP	ASP	ASP	DP
Reference	(9)	(9)	(3)	(10)	(11)	(12)

[a]CMP (atmospheric primary refining).
[b]Maple (60%), birch (20%), beech (20%).
[c]Estimated
[d]SGW = stone grounwood; ASP = alkaline sulfite pretreatment; APP = alkaline peroxide pretreatment
DP = sequential chlorine dioxide-alkaline peroxide interstage treatment.
[e]n.a. = Not available.

VII. Comparison of CTMP[a] properties: spruce[b] *vs*. mixed northern hardwoods[c] (12)

	Spruce	Hardwoods
Brightness	57	72
Yield,[d] %	92	85
C.S. Freeness, mL	250	350
Apparent density, kg/m^3	470	540
Breaking length, km	6.4	4.8
Tear index, $mN \cdot m^2/g$	7.4	6.6

[a]Chemicals applied to coarse pulp from pressurized primary refiner; 4% (spruce) or 3% (hardwood) ClO_2 followed by 8% NaOH containing 2% H_2O_2, all percentages based on dry weight of coarse pulp. Chemical treatment followed by atmospheric refining to near-maximum tensile strength.
[b]Eastern black spruce, containing smaller amounts of balsam fir and jack pine.
[c]Maple (60%), birch (20%), and beech (20%).
[d]Based on dry weight of coarse pulp.

VIII. CMP[a] from hardwood-softwood blends

Hardwood[b] in blend, %	0	20	40	60	80
Breaking length, km	4.9	5.4	4.8	4.2	3.9
Tear index, mN • m^2/g	8.3	8.7	8.9	8.4	7.3
Brightness	58	57	57	56	55
Opacity	89	91	92	93	93

[a]SCMP, Ref. (10).
[b]Softwood: 62% spruce, 25% balsam, 14% jackpine
Hardwood: 62% maple, 13% elm, 13% poplar, 8% beech, 4% others.

IX. Comparison of 15 year old triploid hybrid and 15 year old native aspen growth rates and wood and pulp properties (14).

	Triploid Hybrid Aspen	Native Aspen
Height, m	16.4	13.7
Diameter at breast height, cm	15.8	12.5
Growth rate, m^3 ha^{-1} $year^{-1}$	13.4	6.4
Specific gravity, g/cm^3	0.40	0.35
Screened pulp yield, %	51.2	52.1
Fiber length, mm	1.00	0.79
Breaking length, km	10.4	9.9
Tear index, $mN \cdot m^2/g$	9.4	7.2

X. Comparison of conventional and press dried linerboard properties (15)

Linerboard	Basis Wt., g/m^2	Burst, kPa	Edgewise Compressive Strength, MD/CD
Conventional pine	207	704	19.8/13.2
Oak linerboard, press dried	210	763	28.0/21.2

XI. Comparison of properties of combined boards from conventional and press dried components (15)

Combined Boards	Flat Crush, kPa	Burst (doubleback side up), kPa
100% Pine lens plus conventional medium	186	1481
100% PP oak lens plus 100% PD oak medium	175	1605

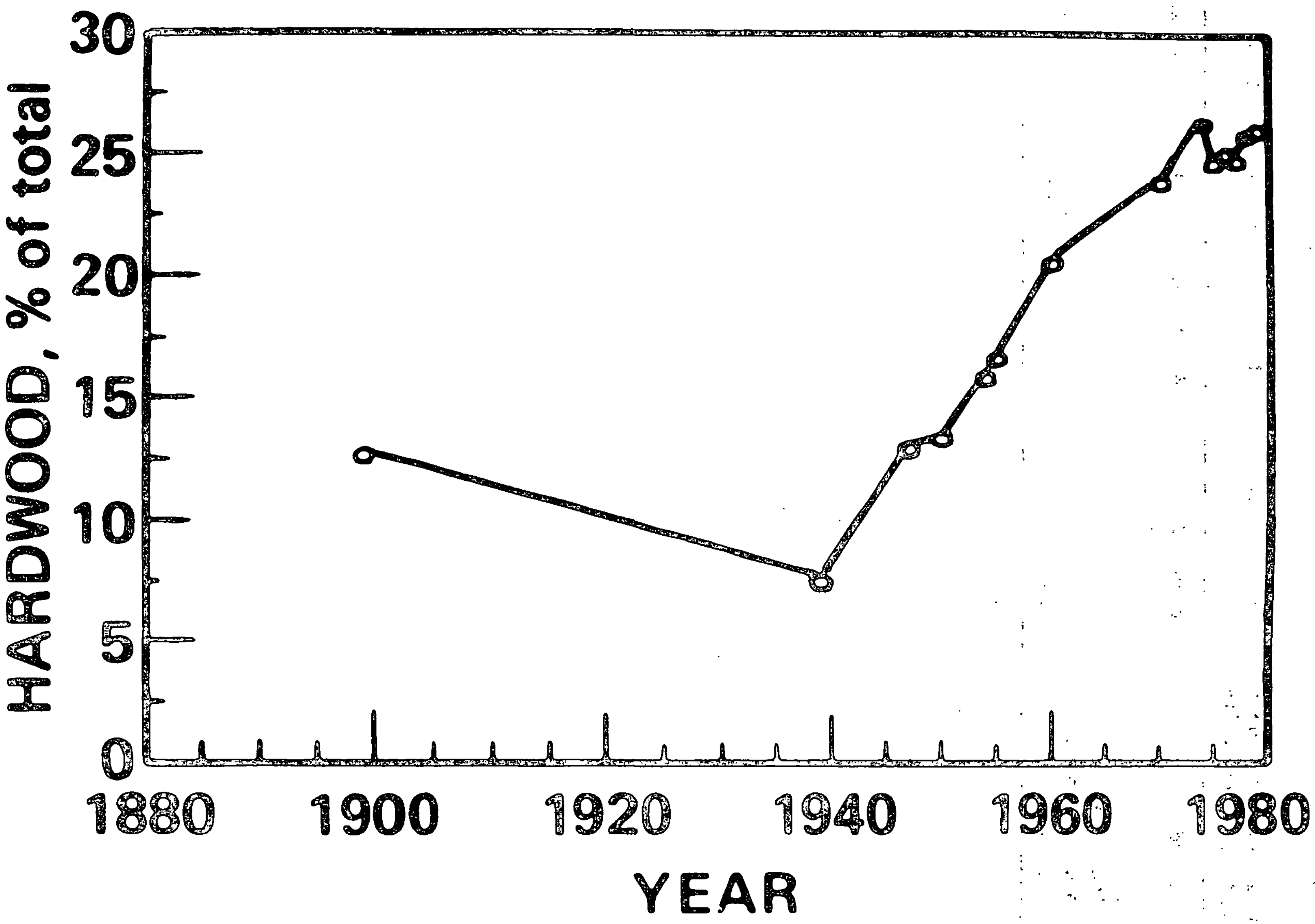

Figure 1. Hardwood pulpwood consumption as a percentage of total pulpwood, 1899-1979.